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THE ECONOMIC SIGNIFICANCE OF NATURAL CROSS-FERTILIZATION IN INDIA

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I. INTRODUCTION.

THE methods of pollination and the possible occurrence of natural cross-fertilization in crops raised from seed are matters of the first importance both in the improvement, introduction and testing of varieties and also in the growth and distribution of seed to cultivators in India. In the present paper it is proposed to place on record some of the more important observations on these questions which have been made during the past four years in the Botanical area at Púsa, and also to discuss the bearing of the facts observed on the methods of improving the crops of India.

The Indian crops, which are raised from seed, fall, for the purposes of this paper, into three great divisions :—

A. Crops with closed flowers, such as the cereals and pulses. In this group self-pollination is likely to be the rule.

B. Crops with hermaphrodite open flowers, such as tobacco, *patwa* (*Hibiscus cannabinus*, L.), linseed, the *Brassica* oil seeds,

til (*Sesamum indicum*, L.), safflower (*Carthamus tinctorius*, L.), niger (*Guizotia abyssinica*, L.), cotton and opium poppy. In this group both self and cross-fertilization are likely.

C. Monœcious and dicecious crops or those in which the male and female flowers are separated; for example, maize, castor oil, *ganja* (*Cannabis indica*, L.) and the various cultivated *Cucurbitaceæ*. In such crops cross-fertilization on a large scale is to be expected.

It is principally with crops belonging to classes A and B that this paper deals.

The evidence on which we have based our opinion as to the occurrence of natural crossing in the crops of India has been entirely obtained from a study of single plant cultures. This is, in our judgment, the most reliable method known at present of obtaining accurate information on the subject. But little work on these lines seems to have been carried out previously due no doubt to the methods of mass selection till recently in vogue and to the time and space involved in the growth of the pure line cultures.

II. CROPS WITH CLOSED FLOWERS.

1. Wheat.

In general, the flowers of all the species and varieties of wheat are self-fertilized, pollination taking place before the extrusion of the anthers. Instances of undoubted natural crossing are rare in regions such as Northern Europe,[1] and some observers even state that it does not take place.[2] Three undoubted cases have been recorded in England and these have been referred to in a recent paper.[3]

While natural crossing seems to be exceedingly rare in damp climates, such as that of England, there is considerable evidence that it is more frequent in drier and more sunny climates like those of the continent of Europe and of North America. Cases of spontaneous crossing have been recorded by Le Couteur[4] in Jersey and by Koernicke[5] at Popplesdorf, while Fruwirth,[6] in a recent work, has brought together most of the recorded examples in the case of the wheat crop. Kiessling,[7] in Bavaria, has recently described eight cases of natural crossing among German wheats, and he considers that its occurrence is more frequent than is generally believed.

In a recent paper[8] we have discussed the occurrence of this phenomenon in India. Four cases of natural crossing were observed in the single ear cultures sown at Lyallpur in 1906, while a

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1 See Darwin, *Animals and Plants under Domestication*, and Biffen, *Journal of Agricultural Science*, Vol. I, 1905, p. 9.

2 See Garton, *Journal of the Farmers' Club*, 1900, p. 47, and De Vries, *Species and Varieties, their origin by Mutation*, 1906, p. 98.

3 Howard & Howard, *Memoirs of the Department of Agriculture in India* (*Botanical Series*), Vol. II, No. 7, 1909.

4 Le Couteur, *The Varieties, Properties and Classification of Wheat*, Jersey, 1872, p. 132.

5 Koernicke, *Die Arten und Varietäten des Getreides*, 1885, s. 31.

6 Fruwirth, *Die Zuchtung der landwirtschaftlichen Kulturpflanzen*, Bd. IV, 1907, s. 91.

7 Kiessling, *Fuhling's landwirtschaftliche Zeitung*, Bd. 57, 1908, s. 737.

further case was proved in 1908 in one of the plots of dwarf wheats at that station. It was further stated that in a large number of the plots at Lyallpur in 1908 (each grown from the produce of single ears sown in 1906), many stray plants were found, often more than one in a plot. These we considered were in all probability natural crosses in the F_1 generation. They have since been grown singly and their offspring examined.[1]

The results, arranged under the botanical variety in which the stray plants were found during the harvest of 1908, are given in the following tables:—

TRITICUM DICOCCUM, SCHRK. VAR. FARRUM, BAYLE.

In one of the plots of white chaff emmer belonging to the above variety three stray ears were found with red chaff. These in 1909 gave rise to the following:—

No.	Parent ear, 1908.	Progeny, 1909.
1	Bearded, chaff smooth red, grain red.	All (5) bearded, chaff smooth, grain red. 1 chaff white, rachis brittle. 2 ,, ,, rachis tough, grain easily shed. 2 chaff red, rachis brittle.
2	Do. do.	All (6) bearded, chaff smooth, grain red. 2 chaff white, rachis brittle. 4 ,, red ,, ,,
3	Do. do.	All (2) bearded, chaff smooth, grain red. 2 chaff red, rachis brittle.

As no red chaff emmer has yet been found in India, it is evident that the ordinary white chaff emmer has been crossed with a red chaff wheat, and probably one with a red grain. These are the only cases of natural crossing in emmer we have observed at Lyallpur. No cases have so far been observed at Púsa, where this variety has been grown for five years.

[1] These cultures were made in the Botanical area at the Cawnpore Experiment Station, as the conditions there are more favourable than at Púsa for the growth of Punjab wheats. We are indebted to Mr. H. M. Leake for facilities extended to us for this work and for the care of the cultures in the *rabi* season of 1908-09.

TRITICUM COMPACTUM, HOST. VAR. ERINACEUM, KCKE.

This bearded variety has smooth red chaff with short bristly spreading awns and small rounded red grains. Twenty-four stray ears were found in 1908 in the plots of this variety and these ears split up in 1909 as follows :—

No.	Parent ear, 1908.	Progeny, 1909.
4	Common wheat, bearded, chaff smooth red, grain red.	All (4) bearded, chaff smooth red, grain red. 2 dwarf wheats. 2 common wheats (one with somewhat rounded grains).
5	Common wheat, slightly bearded, chaff smooth red.	All (6) bearded, chaff smooth red, grain light red. 1 dwarf wheat, grain rounded. 5 common wheats, grain long.
6	Do. do.	All (5) bearded, chaff smooth red, grain red. 1 dwarf wheat. 4 common wheats.
7	Do. do.	All (16) chaff smooth red. 1 dwarf, beardless, very dense, grain red and rounded. 1 dwarf, short bristly awns, grain red and rounded. 3 common wheats, beardless, lax, grain red. 3 common wheats, beardless, lax, grain white. 3 common wheats, very slightly bearded, grain red. 1 common wheat, very slightly bearded, grain white. 1 common wheat, slightly bearded, grain red. 3 common wheats, fully bearded, grain red.
8	Do. do.	All (8) with smooth chaff. 1 dwarf wheat, beardless, chaff white, grain white. 1 dwarf wheat, beardless, chaff red, grain red. 1 intermediate between a dwarf and common wheat, bearded, glumes white and rounded, grain red. 1 common wheat, beardless, lax, chaff red, grain white. 4 common wheats, slightly bearded, chaff red, grain red.
9	Dwarf wheat, bearded, chaff felted red, grain red.	All (2) common wheats, bearded, chaff felted, grain red. 1 chaff densely felted red. 1 chaff felted white.
10	Do. do.	All (7) bearded, chaff felted, grain red. 1 dwarf wheat. 4 common wheats, chaff red. 2 common wheats, chaff white.
11	Do. do.	All (5) common wheats, bearded with red grain. 2 chaff felted red. 2 „ „ white. 1 chaff smooth red.
12	Do. do.	All (2) bearded, chaff densely felted. 1 dwarf wheat. 1 common wheat, chaff red, grain red.
13	Do. do.	All (4) common wheats, chaff densely felted red, grain red. 2 ears lax. 2 ears dense.

No.	Parent ear, 1908.	Progeny, 1909.
14	Dwarf wheat, bearded, chaff felted red, grain red.	All (4) bearded, chaff felted, grain red. 2 dwarf wheats, chaff slightly felted red. 1 common wheat, chaff densely felted white. 1 common wheat, lax, chaff red.
15	Do. do.	All (9) bearded, chaff felted, grain red. 1 dwarf wheat, chaff felted red, grain very rounded. 1 intermediate between a dwarf and common wheat, chaff densely felted red, grain rounded. 1 common wheat, chaff densely felted red, grain rounded. 1 common wheat, chaff red, grain not rounded. 1 common wheat, chaff sparsely felted, grain large and much rounded. 4 common wheats, chaff white, grain rounded.
16	Do. do.	All (2) bearded, chaff felted white, grain red. 1 dwarf wheat, grain rounded. 1 common wheat, grain long.
17	Do. do.	All (9) bearded, chaff felted, grain red. 2 dwarf wheats, chaff reddish, grain rounded. 1 common wheat, very dense, chaff densely felted reddish, grain rounded. 1 common wheat, similar to the above, but with lightly felted chaff. 3 common wheats, dense, chaff densely felted red. 1 common wheat, similar to the above, but grain very rounded. 1 common wheat, medium, chaff white, grain long.
18	Do. do.	All (3) bearded, chaff red, grain red. 1 dwarf wheat, chaff smooth. 1 common wheat, chaff smooth, grain rounded. 1 common wheat, chaff very densely felted.
19	Do. do.	Four plants obtained. 1 dwarf, bearded, chaff smooth white, grain red. 1 common wheat, beardless, chaff smooth red, grain white and rounded. 1 common wheat, bearded, chaff lightly felted red, grain red. 1 common wheat, bearded, chaff densely felted red, grain red and rounded.
20	Do. do.	All (8) bearded, chaff densely felted red, grain red. 1 dwarf wheat. 1 intermediate between a dwarf and a common wheat. 1 common wheat, dense, grain rounded. 5 common wheats, grain long.
21	Do. do.	All (17) bearded, chaff felted. 1 dwarf wheat, chaff lightly felted white, grain white and rounded. 2 dwarf wheats, chaff densely felted white, grain red and rounded. 4 dwarf wheats, chaff densely felted red, grain red and rounded. 7 common wheats, chaff densely felted red, grain red. 2 common wheats, chaff lightly felted red, grain red. 1 common wheat, chaff felted white, grain red.

No.	Parent ear, 1908.	Progeny, 1909.
22	Dwarf wheat, bearded, chaff felted red, grain red.	All (7) bearded, chaff felted, grain red. 2 dwarf wheats, slightly bearded, chaff red. 1 dwarf wheat, slightly bearded, chaff white. 2 common wheats, chaff red. 2 „ „ chaff white.
23	Do. do.	All (9) bearded, grain red. 2 dwarf wheats, chaff felted red. 2 common wheats, chaff lightly felted white. 3 „ wheats, chaff felted white. 1 „ „ chaff densely felted red. 1 „ „ chaff smooth red.
24	Do. do.	All (15) bearded, chaff felted, grain red. 1 dwarf wheat, chaff densely felted white. 1 „ „ chaff „ „ red. 1 „ „ chaff lightly „ white. 1 „ „ „ „ „ red. 1 „ „ chaff felted red. 3 common wheats, chaff felted white. 2 „ „ chaff lightly felted red. 5 „ „ chaff densely felted red.
25	Do. do.	All (5) bearded, grain red. 1 dwarf wheat, chaff smooth red. 2 common wheats, chaff felted red. 2 „ „ „ „ white.
26	Do. do.	All (12) bearded, grain red. 1 dwarf wheat, chaff densely felted red. 1 „ „ „ lightly felted white. 1 „ „ „ smooth white. 1 intermediate between a dwarf and common wheat, chaff felted red, grain rounded. 4 common wheats, chaff densely felted red. 4 „ „ „ lightly „ red.
27	Do. do.	All (8) bearded, chaff felted, grain red. 2 dwarf wheats, chaff red. 1 common wheat, dense, chaff densely felted white. 1 „ „ dense, chaff white. 1 „ „ „ chaff lightly felted red. 3 „ wheats, medium, chaff felted red.

Triticum compactum, Host. var. linaza, Kcke.

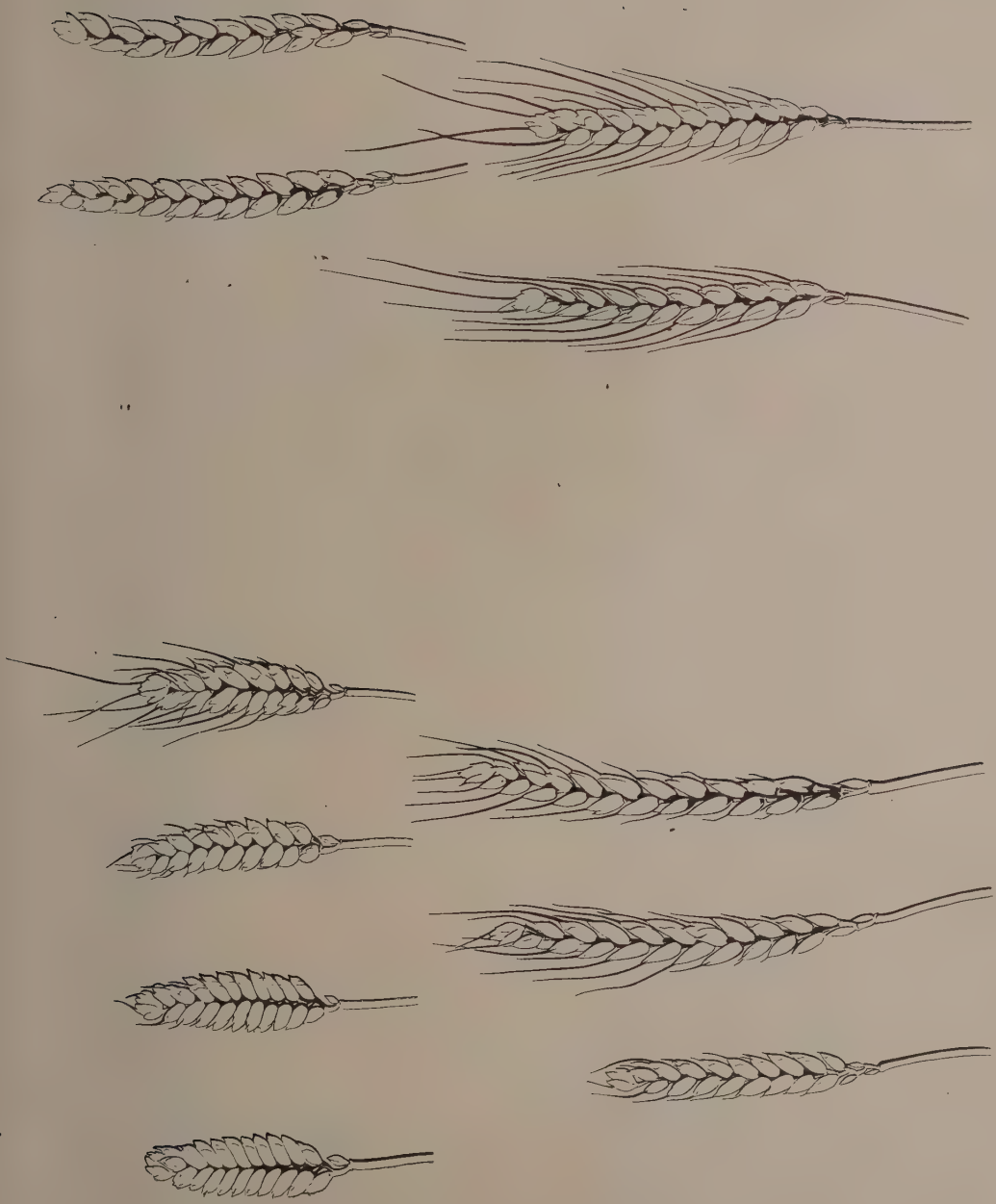
In one of the plots of beardless felted white chaff dwarf wheat with a white grain belonging to this variety one stray plant was found in 1908, which in 1909 split up as follows :—

No.	Parent ear, 1908.	Progeny, 1909.
28	Common wheat, beardless, chaff felted red, grain white.	All (4) beardless, chaff lightly felted, grain white. 1 dwarf wheat, chaff red. 2 common wheats, chaff red. 1 „ „ „ white.

Triticum compactum, Host. var. Humboldti, Kcke.

In this dwarf variety the ears are beardless with smooth white chaff and amber-coloured grain. Eight stray plants were found in 1908, which gave rise to the following progeny in 1909 :—

No.	Parent ear, 1908.	Progeny, 1909.
29	Dwarf wheat, slightly bearded, chaff smooth red, grain white.	All (23) chaff smooth white, grain white. (Plate 1.) 1 dwarf wheat, bearded. 6 dwarf wheats, slightly bearded. 1 dwarf wheat, beardless. 5 intermediate wheats, bearded. 2 „ „ slightly bearded. 2 „ „ beardless. 3 common wheats, bearded. 2 „ „ slightly bearded. 1 „ wheat, beardless.
30	Do. do.	All (2) chaff smooth, grain white. 1 dwarf wheat, beardless, chaff red. 1 common wheat, slightly bearded, chaff white.
31	Do. do.	All (5) chaff smooth red, grain white. 2 dwarf wheats, beardless. 1 „ wheat, bearded. 1 common wheat, slightly bearded. 1 „ „ fully bearded.
32	Dwarf wheat, bearded, chaff felted white, grain red.	All (6) chaff felted white, grain red. 1 dwarf wheat, beardless. 3 common wheats, slightly bearded. 2 „ „ fully bearded.
33	Dwarf wheat, beardless, chaff felted red, grain white.	All (13) beardless, grain white. 1 dwarf wheat, chaff smooth white. 2 „ „ chaff felted red. 2 common wheats, chaff felted white 2 „ „ chaff smooth red. 6 „ „ chaff felted red.
34	Dwarf wheat, very slightly bearded, chaff felted white, grain red.	All (11) chaff white, grain red. 1 dwarf wheat, beardless, chaff densely felted. 1 intermediate wheat, glumes smooth and rounded. 2 common wheats, beardless, chaff densely felted. 3 „ „ slightly bearded, chaff felted. 4 „ „ fully bearded, chaff densely felted.
35	Common wheat, beardless, chaff smooth white, grain white.	All (10) beardless, chaff smooth white, grain white. 1 dwarf wheat, grain rounded. 7 common wheats, grain long. 2 „ „ grain rounded.
36	Do. do.	All (3) beardless, chaff smooth white, grain white. 1 dwarf wheat. 1 common wheat, medium. 1 „ „ very lax.



THE PROGENY OF A SLIGHTLY BEARDED DWARF WHEAT (No. 29).

TRITICUM VULGARE, VILL. VAR. ERYTHROSPERMUM, KCKE.

In the plots of this variety, the ears of which are bearded with smooth white chaff and red grain, a large number of stray plants were found in 1908. Their behaviour after sowing is given below :—

No.	Parent ear, 1908.	Progeny, 1909.
37	Bearded, awns black, chaff reddish, grain red.	All (4) bearded, chaff felted, grain red. 1 chaff reddish, grain like that of a macaroni wheat. 2 chaff densely felted white. 1 very late plant, chaff slightly felted reddish.
38	Bearded, chaff felted white, grain red.	All (2) bearded, chaff felted white, grain red. 1 chaff very densely, felted. 1 „ felted.
39	Beardless, chaff smooth red, grain white.	All (7) chaff smooth red, white grain. The seven plants differ in the degree of bearding.
40 to 76	Bearded, awns blackish, chaff white variously felted, grain red.	The progeny of these 36 plants varied in the degree of felting, in the density of the ear or in both of these respects. In crosses made between Punjab type 9 (felted wheat), and smooth chaff common wheats we have found in the F_2 generation a great preponderance of felted ears (100 felted to 7 smooth). There is every possible gradation between the densely felted and smooth ears in the F_2 generation, and the above examples of natural crossing bear a strong resemblance to the F_2 generation of our artificial crosses referred to. We have no doubt that all the 36 are true cases of natural crossing.
77	Beardless, chaff smooth red, grain red.	All (14) smooth chaff. 2 beardless, chaff white, grain red. 10 „ „ reddish, „ „ 1 „ „ „ „ white. 1 slightly bearded, chaff red, grain red.
78	Slightly bearded, chaff smooth red, grain red.	All (7) chaff smooth, grain red. 1 beardless, chaff white. 1 „ „ red. 1 half bearded, chaff white. 3 „ „ „ red. 1 bearded, chaff red.
79	Do. do.	All (8) chaff smooth. 1 slightly bearded, chaff red, grain red. 6 half bearded, chaff red, grain red. 1 bearded, chaff white, grain white.
80	Bearded, awns black, chaff felted white, grain red.	All (14) bearded, chaff white, grain red. 9 chaff densely felted. 5 „ lightly felted.
81	Do. do.	All (3) bearded, chaff white, grain red. 2 chaff felted. 1 „ smooth.
82 to 85	Bearded, chaff felted white, grain red.	In these cases the progeny varied in the degree of felting only.

No.	Parent ear, 1908.		Progeny, 1909.
86	Bearded, chaff felted white, grain red.		All (6) bearded, chaff white, grain red. 1 chaff smooth. 1 ,, lightly felted. 1 ,, moderately felted. 3 ,, densely felted.
87	Do.	do.	All (11) bearded, chaff white, grain red. 2 chaff smooth. 6 ,, lightly felted. 3 ,, moderately felted.
88	Do.	do.	All (5) bearded, chaff white, grain red. 2 lax, chaff densely felted. 2 chaff moderately felted. 1 ,, lightly felted.
89	Do.	do.	All (6) bearded, chaff white, grain red. 2 medium, densely felted. 1 lax, felted. 1 medium, lightly felted. 2 lax, smooth.
90	Do.	do.	All (7) bearded, lax, chaff white, grain red. 1 chaff smooth. 4 ,, lightly felted. 1 ,, moderately felted. 1 ,, densely felted.
91	Do.	do.	All (9) bearded, lax, chaff white, grain red. 7 chaff densely felted. 1 ,, moderately felted. 1 ,, smooth.
92	Do.	do.	All (9) bearded, chaff white, grain red. 1 chaff smooth. 3 ,, lightly felted. 5 ,, densely felted.
93	Do.	do.	All (11) bearded, chaff white, grain red. 2 chaff smooth. 4 ,, lightly felted. 5 ,, felted.
94	Do.	do.	All (11) bearded, chaff white, grain red. 2 chaff smooth. 4 ,, lightly felted. 5 ,, felted.
95	Do.	do.	All (10) bearded, chaff white, grain red. 1 chaff smooth. 2 ,, very lightly felted 2 ,, lightly felted. 2 ,, moderately felted 3 ,, densely felted
96	Do.	do.	All (7) bearded, chaff white, grain red. 1 chaff smooth. 2 ,, lightly felted. 4 ,, felted.
98 and 99	Do.	do.	All bearded, chaff felted white, grain red. In these two cases the plants varied in the degree of felting only.

No.	Parent ear, 1908.	Progeny, 1909.
100	Bearded, chaff felted white, grain red.	All (4) bearded, chaff white, grain red. 1 dense, chaff densely felted. 3 lax, chaff slightly felted.
101	Bearded, lax, chaff felted white, grain red.	All (6) chaff white, grain red. 1 beardless, medium, chaff very densely felted 1 beardless, lax, chaff moderately felted. 1 slightly bearded, medium, chaff very densely felted. 1 slightly bearded, medium, chaff moderately felted. 2 bearded, chaff densely felted.
102	Do. do.	All (7) bearded, lax, grain red. 1 chaff almost smooth. 3 „ lightly felted. 3 „ moderately felted.
103	Do. do.	All (6) bearded, lax, chaff white, grain red. 1 chaff smooth. 3 „ lightly felted. 2 „ moderately felted.
104	Do. do.	All (11) bearded, lax, chaff white, grain red. 4 chaff smooth. 7 „ lightly felted.
105	Do. do.	All (2) bearded, lax, chaff white, grain red. 1 chaff densely felted. 1 „ lightly felted.
106	Do. do.	All (5) bearded, lax, chaff white, grain red. 1 chaff felted. 4 „ lightly felted.
107 to 111	Do. do.	In these five cases the progeny differed in the degree of felting only.
112	Do. do.	All (5) bearded, chaff white, grain amber-coloured. 3 black awns, chaff densely felted. 1 white „ „ moderately felted. 1 „ „ „ very slightly felted.
113	Do. do.	All (5) bearded, chaff slightly felted white, grain red. 3 medium. 2 lax.
114	Do. do.	All (4) bearded, chaff white, grain red. 1 lax, chaff densely felted. 1 „ „ lightly felted. 1 „ „ smooth. 1 dense, chaff densely felted, grain short.
115 to 118	Bearded, chaff smooth red, grain red.	In these four cases the progeny was bearded, with smooth chaff and red grain. Red chaff and white chaff plants however occurred in each case.
119	Do. do.	All (7) bearded, chaff smooth. 2 chaff red, grain red. 2 „ „ grain white. 2 „ white, grain white. 1 „ „ „ red.

No.	Parent ear, 1908.	Progeny, 1909.
120	Bearded, chaff smooth red, grain red.	All (3) bearded, chaff smooth *white* and grain red. In this case a red chaff parent has given white chaff offspring.
121	Slightly bearded, chaff smooth white, grain red.	All (2) chaff smooth white. 1 beardless, grain red. 1 slightly bearded, grain white
122	Do. do.	All (5) chaff smooth white. 1 beardless, lax, grain white. 1 slightly bearded, lax, grain red. 1 „ „ „ white. 1 „ „ medium, grain white. 1 bearded, lax, grain white.
123	Slightly bearded, chaff felted red, grain red.	All (6) chaff smooth red, grain red. 1 fully bearded. 1 half bearded. 1 very slightly bearded. 3 beardless.
124	Ears square, bearded with black awns, chaff felted white, grain red.	All (2) bearded, chaff densely felted white, grain red. 1 lax. 1 dense.
125	Do. do.	All (7) bearded, lax, chaff white, grain red. 5 chaff densely felted, awns black. 1 „ slightly felted, awns white. 1 „ smooth, awns white.
126	Do. do.	All (17) bearded, chaff white, grain red 8 chaff densely felted. 4 „ moderately felted. 3 „ slightly felted. 2 „ smooth.
127	Do. do.	All (8) bearded, chaff white, grain red. 4 chaff densely felted, awns black. 3 „ moderately felted, awns black. 1 „ slightly felted, awns white.
128	Do. do.	All (16) bearded, white chaff, grain red. 5 chaff densely felted. 2 „ less densely felted. 7 „ slightly felted. 2 „ smooth.
129	Do. do.	All (19) bearded, chaff white, grain red. 2 chaff smooth. 4 „ slightly felted. 5 „ moderately felted. 8 „ densely felted.
130	Do. do.	All (12) bearded, chaff white, grain red. 10 chaff felted (density of ear and degree of felting varies). 2 chaff smooth.
131 and 132	Do. do.	All bearded, chaff felted white, grain red. In these two cases the plants differed in density and in the degree of felting.

No.	Parent ear, 1908.	Progeny, 1909.
133 to 136	Bearded, chaff felted white, grain red.	All (5) bearded, chaff white, grain red. In all cases the plants differed in the degree of felting only.
137	Do. do.	All (8) bearded, chaff white, grain red. 3 chaff densely felted. 4 ,, moderately felted. 1 ,, smooth.
138	Do. do.	All (10) bearded, chaff white, grain red. 5 chaff densely felted. 4 ,, slightly felted 1 ,, smooth.
139	Do. do.	All (12) bearded, chaff white, grain red. 8 chaff densely felted. 3 ,, slightly felted. 1 ,, smooth.

TRITICUM VULGARE, VILL. VAR. ERYTHROLEUCON, KCKE.

In this bearded variety with felted red chaff and white grain, twelve cases of natural crossing were discovered in 1908. The progeny of these stray plants in 1909 is described below :—

No.	Parent ear, 1908.	Progeny, 1909.
140	Plant like a macaroni wheat with felted reddish chaff and white grain.	All (4) bearded, awns black, chaff red, outer glumes sharply keeled to the base. 1 dense, rounded felted glumes, no grain. 1 lax, chaff smooth, no grain. 1 ,, chaff felted, grain white. 1 ,, black awns, straw solid, chaff felted.
141	Bearded, chaff felted reddish, grain red.	All (8) bearded, grain red. 4 chaff felted red. 2 ,, ,, white 2 ,, smooth red.
142 to 146	Beardless, chaff smooth red, grain white.	In all five cases the chaff was smooth and the grain white. In all instances red and white chaff and beardless and variously bearded plants occurred.
147	Slightly bearded, chaff smooth red, grain white.	All (6) chaff smooth red, grain white. 1 beardless. 1 slightly bearded. 3 half bearded. 1 fully bearded.
148	Do. do.	All (8) chaff smooth, grain white. 4 beardless, chaff red. 1 slightly bearded, chaff white. 3 half bearded, chaff red.
149	Bearded, chaff felted red, grain red.	All (10) bearded, chaff red. 1 chaff smooth, grain red. 7 ,, densely felted, grain red. 2 ,, ,, ,, ,, white.

No.	Parent ear, 1908.	Progeny, 1909.
150	Bearded, chaff felted red, grain red.	All (7) bearded, red grain. 1 chaff red smooth. 1 ,, red slightly felted. 2 ,, ,, densely ,, 2 ,, white slightly ,, 1 ,, ,, very densely felted.
151	Do. do.	All (12) bearded. 3 chaff densely felted white, grain red. 1 ,, moderately felted white, grain red. 4 ,, densely felted red, grain red. 3 ,, slightly felted red, grain red. 1 ,, smooth red, grain white.

TRITICUM VULGARE, VILL. VAR. GRAECUM, KCKE.

In the plots of this bearded variety with smooth white chaff and white grain a large number of aberrant plants were found in 1908 which split up in 1909 as follows :—

No.	Parent ear, 1908.	Progeny, 1909.
152	Beardless, chaff smooth white, grain white.	All (7) chaff smooth white, grain white. 5 beardless. 1 half bearded. 1 fully ,,
153	Slightly bearded, chaff red slightly felted, grain red.	All (5) chaff slightly felted, grain white. 1 bearded, chaff white. 1 beardless, ,, ,, 3 slightly bearded, chaff red.
154	Do. do.	All (3) slightly bearded, lax, grain white. 1 chaff red felted. 1 ,, white smooth. 1 ,, felted white.
155	Bearded, chaff smooth red, grain white.	All (9) bearded, chaff smooth grain white. 6 chaff red. 3 ,, white.
156 and 157	Bearded, chaff felted white, grain red.	All bearded, chaff felted white, grain red. In both cases the various plants differed in the degree of felting.
158	Do. do.	All (11) bearded, chaff white. 6 densely felted, grain red. 1 densely ,, ,, white. 4 slightly ,, ,, red.
159	Do. do.	All (6) bearded, chaff white, grain red. 1 chaff smooth. 2 ,, lightly felted. 3 ,, densely ,,
160	Do. do.	All (11) bearded, chaff white, grain red. 1 chaff smooth.

No.	Parent ear, 1908.	Progeny, 1909.
		2 chaff slightly felted. 6 ,, moderately felted. 2 ,, densely felted.
161	Bearded, chaff felted white, grain red.	All (7) bearded, chaff white. 1 chaff smooth, grain red. 1 ,, ,, ,, white. 3 moderately felted, grain red. 1 densely felted, grain red. 1 ,, ,, ,, white.
162	Bearded, awns black, chaff felted white, grain red.	All (11) bearded, chaff white, grain red. All the plants differed in the degree of felting and in the density of the ear.
163 ,,	Do. do.	All (16) bearded, chaff white. 2 chaff densely felted, grain red and rounded. 1 ,, densely felted, grain white. 6 ,, moderately felted, grain red. 1 ,, slightly felted, grain white. 3 ,, slightly felted, grain red. 1 ,, ,, ,, red and rounded. 2 ,, smooth, grain white.
164 to 166	Bearded, chaff felted white, grain red.	All bearded, chaff white. In each case the plants differed both in the degree of felting and in the colour (red or white) of the grain.
167	Do. do.	All (17) bearded, chaff white. 2 chaff smooth, grain white. 10 ,, felted, ,, red. 5 ,, ,, ,, white.
168	Do. do.	All (5) bearded, chaff white, grain red. 1 chaff smooth, grain rounded. 1 ,, slightly felted, grain rounded 2 ,, ,, ,, grain long. 1 ,, densely felted.
169	Do. do.	All (14) bearded, chaff white. 2 chaff densely felted, grain white. 1 ,, slightly felted, grain white. 5 ,, densely felted, grain red. 4 ,, moderately felted, grain red 1 ,, slightly felted, grain red. 1 ,, smooth, grain red.
170	Bearded, chaff slightly felted red, grain red.	All (15) bearded. 1 chaff red smooth, grain red. 7 ,, ,, felted ,, ,, 6 ,, white felted ,, ,, 1 ,, ,, ,, ,, white.
171	Do. do.	All (6) bearded, lax, chaff smooth red. 5 grain red. 1 ,, white.
172	Do. do.	All (9) bearded, lax. 2 chaff smooth red, grain red. 4 ,, very slightly felted red, grain red. 1 ,, slightly felted red, grain white. 1 ,, moderately felted red, grain red. 1 ,, moderately felted white, grain red.

No.	Parent ear, 1908.	Progeny, 1909.
173	Bearded, chaff slightly felted red, grain red.	All (10) bearded. 1 chaff smooth white, grain white. 2 ,, ,, ,, red. 2 ,, smooth red, grain white. 3 ,, ,, ,, red. 2 ,, slightly felted red, grain red.
174	Do. do.	All (10) bearded. 3 chaff smooth red, grain white. 1 ,, ,, ,, red. 1 ,, slightly felted red, grain white. 5 ,, smooth white, grain red.
175	Do. do.	All (11) bearded, chaff very slightly felted red. 5 grain white. 6 ,, red.
176	Do. do.	All (8) bearded. 1 chaff slightly felted red, grain white. 1 ,, smooth, red. 5 ,, slightly felted red, grain red. 1 ,, slightly felted white, grain white.

TRITICUM VULGARE, VILL. VAR. ALBORUBRUM, KCKE.

In one of the plots of this beardless variety with smooth red chaff and white grain one aberrant plant was found in 1908 which split, in 1909, as follows :—

No.	Parent ear, 1908	Progeny, 1909.
177	Bearded, chaff reddish smooth, grain white.	All (2) bearded with smooth white chaff and white grain.

TRITICUM VULGARE, VILL. VAR. FULIGINOSUM, AL.

In the plots of this variety (bearded, densely felted grey chaff and red grain) on the Lyallpur farm, a large number of aberrant plants were found in 1908 which, when sown separately, behaved as follows :—

No.	Parent ear, 1908.	Progeny, 1909.
178	A macaroni like wheat, bearded, chaff smooth reddish, grain white.	All (3) bearded, chaff smooth, grain white. 2 chaff red. 1 ,, white.
179	Bearded, lax, chaff felted white, grain red.	All (12) bearded, lax, chaff white, grain red. 8 chaff very densely felted. 4 ,, less ,, ,,

No.	Parent ear, 1908.	Progeny, 1909.
180	Bearded, chaff red felted, grain white.	All (24) bearded, grain white. 4 chaff densely felted white. 14 ,, less densely felted red. 6 ,, slightly felted red.
181	Do. do.	All (8) bearded, grain white. 1 chaff felted white. 3 ,, densely felted red. 3 ,, felted light-red. 1 ,, lightly felted red.
182	Do. do.	All (13) bearded, chaff felted, grain white. 5 chaff white. 8 ,, red.
183	Slightly bearded, chaff felted white, grain red.	All (4) chaff white felted, grain white. 2 bearded. 1 slightly bearded. 1 beardless.
184	Do. do.	All (4) chaff felted white. 1 bearded, grain red. 1 slightly bearded, grain red. 1 beardless, grain red. 1 ,, grain white.
185	Do. do.	All (8) chaff white, grain red. 2 bearded, chaff densely felted. 1 ,, chaff slightly ,, 3 slightly bearded, chaff densely felted. 2 beardless, chaff densely felted.
186	Do. do.	All (5) densely felted, chaff white, grain red. 1 beardless. 2 slightly bearded. 2 bearded.
187	Do. do.	All (13) densely felted, chaff white, grain red. 2 beardless. 8 slightly bearded. 3 fully ,,
188	Do. do.	All (2) chaff white, grain red. 1 slightly bearded, chaff densely felted. 1 fully bearded, chaff moderately
189	Do. do.	All (12) chaff white variously felted. 3 fully bearded, grain dark amber. 1 fully bearded, ,, clear white. 4 half bearded. 3 slightly ,, 1 beardless.
190	Do. do.	All (10) felted, chaff white. 1 fully bearded, grain white. 1 slightly bearded, ,, ,, 4 ,, ,, ,, red. 3 beardless, grain red. 1 ,, ,, white.
191	Do. do.	All (5) chaff variously felted white, grain red. 1 dwarf wheat, bearded, grain rounded.

No.	Parent ear, 1908.	Progeny, 1909.
		1 dwarf wheat, rather lax, beardless, grain long. 1 intermediate wheat, grain rounded. 1 „ „ „ long. 1 common beardless wheat, grain long.
192	Slightly bearded, chaff felted white, grain red.	All (14) chaff variously felted white, grain red. 2 bearded. 6 slightly bearded. 6 beardless.
193	Do. do.	All (9) chaff felted white. 2 bearded, grain red. 1 „ „ white. 4 slightly bearded, grain red. 2 beardless, grain red.
194	Beardless, chaff felted white, grain red.	All (14) beardless, chaff white, grain red. 6 chaff smooth. 4 „ felted 4 „ slightly felted.
195 to 198	Do. do.	All beardless, chaff white, grain red. The plants in each culture differed in the degree of felting only.
199	Do. do.	All (3) beardless, chaff densely felted white, grain red. 2 dense ears. 1 very lax ear.
200	Slightly bearded, chaff felted red, grain red.	All (24) chaff densely felted, grain red. 2 bearded, dense, chaff red. 2 „ chaff white. 13 slightly bearded, chaff red. 7 beardless, chaff red.
201	Do. do.	All (20) chaff red, grain red. 2 bearded, chaff slightly felted. 7 slightly bearded, chaff variously felted. 3 slightly bearded, „ smooth. 3 beardless, chaff felted. 5 „ „ smooth.
202	Do. do.	All (12) moderately felted, chaff reddish, grain red. 2 beardless. 5 slightly bearded. 5 bearded.
203	Do. do.	All (14) chaff red. 1 beardless, chaff densely felted, grain white. 2 beardless, „ slightly felted, grain red. 4 beardless, „ densely „ „ „ 2 slightly bearded, chaff moderately felted, grain red. 3 slightly bearded, „ slightly felted, „ „ 1 bearded, chaff slightly felted, grain red. 1 bearded, „ moderately felted, grain red.
204	Do. do.	All (12) chaff variously felted. 1 slightly bearded, chaff white, grain red. 3 beardless, chaff white, grain red. 1 „ „ „ grain white. 6 „ „ red, grain red. 1 „ very dense, chaff red, grain red.

No.	Parent ear, 1908.	Progeny, 1909.
205	Slightly bearded, chaff felted red or reddish, grain red.	All (6) chaff felted, grain red. 2 beardless, chaff white. 2 „ „ red. 1 slightly bearded, chaff red. 1 half „ „
206	Do. do.	All (10) chaff felted. 3 slightly bearded, chaff red, grain red. 2 „ „ „ „ white. 1 „ „ „ white, grain red. 2 bearded, chaff red, grain red. 2 „ „ white, grain „
207	Do. do.	All (22) chaff felted. 1 bearded, chaff red, grain white. 1 „ „ „ „ red. 1 „ „ white, „ „ 9 slightly bearded, chaff red, grain red. 4 slightly bearded, chaff white, grain red. 4 beardless, chaff red, grain red. 2 „ chaff white, „ „
208	Do. do.	All (6) chaff felted, grain red. 1 beardless, chaff white. 1 „ „ red. 3 slightly bearded, chaff red. 1 „ „ „ white.
209	Do. do.	All (18) chaff felted. 1 beardless, dense, chaff red, grain red and rounded. 1 „ medium, chaff red, grain red and long. 1 „ lax, chaff red, grain „ „ 1 slightly bearded, chaff red, grain white. 10 „ „ „ „ „ 1 „ „ chaff white, grain red. 1 bearded „ „ „ „ 2 „ chaff red, grain red.
210	Do. do.	All (11) chaff white. 3 half bearded, chaff densely felted, grain red. 1 half bearded, chaff slightly „ „ „ 1 slightly bearded, chaff slightly felted, grain white. 4 beardless, chaff densely felted, grain red. 1 „ „ „ „ „ 1 „ „ smooth, grain red.
211	Do. do.	All (10) chaff felted, grain red. 6 slightly bearded. 4 beardless.
212	Do. do.	All (4) chaff felted, grain red. 1 beardless, dense, chaff red. 1 slightly bearded, lax, chaff white. 1 „ „ „ „ red. 1 bearded, very lax, grain like that of a durum wheat.
213	Do. do.	All (3) chaff densely felted, grain red. 1 beardless, chaff white. 1 half bearded, chaff red. 1 bearded, chaff white.

No.	Parent ear, 1908.	Progeny, 1909.
214	Slightly bearded, chaff felted red or reddish, grain red.	All (7) chaff variously felted white. 1 beardless, grain white. 3 „ „ red. 2 slightly bearded, grain red. 1 half bearded „ „
215	Do. do.	All (11) chaff variously felted, grain red 1 beardless, chaff red. 1 slightly bearded, chaff white. 5 „ „ „ red. 4 fully bearded, chaff red.
216	Do. do.	All (5) chaff variously felted, grain red. 1 half bearded, chaff white. 2 „ „ „ red. 2 fully bearded, chaff red.
217 to 221	Beardless, chaff felted, grain red.	In these five cases all the plants were beardless, with red felted chaff and red grain. They differed in the density of the ear and in the degree of felting.
222	Do do.	All (9) chaff felted, grain red. 2 slightly bearded, chaff red. 2 „ „ „ white. 4 beardless, chaff red. 1 „ „ white.
223	Do. do.	All (4) chaff variously felted. 2 beardless, chaff red, grain red. 1 slightly bearded, chaff white, grain white. 1 bearded, chaff white, grain red.
224	Do. do.	All (4) chaff variously felted, grain red. 1 slightly bearded, chaff white. 3 beardless, chaff reddish.
225	Do. do.	All (2) beardless, dense, chaff red, grain red. 1 chaff smooth. 1 „ slightly felted.
226	Do. do.	All (12) grain red. 2 beardless, chaff felted red 1 slightly bearded, chaff slightly felted white. 1 „ „ densely „ „ 3 „ moderately felted red. 1 beardless, chaff red smooth. 4 „ „ slightly felted.

Five cases of natural crossing in wheat in Bihár have been proved. In 1908, 130 single ear cultures of the wheats of Bengal were sown in the Botanical area at Púsa. Four of these proved to be natural crosses. One of the ears was obtained from a culture which had been grown for a year at Púsa, the other three were grown from ears found in the cultivators' fields in North Bihár. The fifth case of natural crossing occurred at Púsa

in a plot of wheat which had been grown from one plant selected in 1906.

The three cases of natural crossing in cultivators' fields in North Bihár were as follows: In the first case, a bearded smooth red chaff ear, sown in 1908, split up into red and white chaff plants in 1909. In the second case, one ear of a black awned common wheat with blackish chaff, sown in 1908, gave rise in 1909 to two kinds of plants—plants with black chaff on a red ground and plants with black chaff on a white ground. One of each of these two classes of plants were sown in 1909 and during the present year (1910) both have split still further. The plant with black chaff on a white ground gave white chaff plants as well as plants like the parent ear. The plant with black chaff on a red ground gave four classes of plants, white chaff, red chaff, black chaff on a white ground, and black chaff on a red ground. The third case was observed in a bearded smooth chaff ear sown in 1908 which gave rise to apparently uneven progeny in 1909. It was not possible to determine with certainty the characters of the chaff of the progeny of this culture in 1909 as the plants ripened late and were not fully developed. Eight single plants were selected and sown separately in October 1909. Six of these came uniform like the original parent and two split, one into red and white chaff and the other into red, white, black on white and black on red chaff.

The two cases of natural crossing which have been proved in the Botanical area at Púsa are the following. A slightly bearded white chaff plant was observed in 1909 in one of the plots raised from a single ear in 1906. This when sown separately gave slightly bearded, beardless and fully bearded ears in 1910. The second case was observed in one of the single ear cultures of Bengal wheats in 1909 when a white chaff bearded ear gave bearded white chaff plants, and one black chaff plant in 1909. This latter sown separately in the same year gave, in 1910, both white and black chaff plants.

In addition to the five cases of natural crossing at Púsa described above, a number of stray plants were found both in 1909 and again in 1910 in some of the larger plots originally grown from one plant in 1906. As these strays differed from any wheats grown at Púsa we are inclined to believe they were natural crosses. Time and space did not permit us to grow them on and prove their origin and they were accordingly thrown away. Natural crossing in wheat undoubtedly takes place at Púsa to a small extent, but its occurrence bears no comparison to the frequency of this phenomenon at Lyallpur.

It will be evident from the above that natural crossing in wheat is far more frequent under the conditions obtaining on the Canal Colonies of the Punjab than it is in Bihár. At Púsa five cases have been proved. Two hundred and thirty-one cases were proved by us at Lyallpur, and of these no less than two hundred and twenty-six took place in 1907. In the dry climate of the Chenab Colony wheat is grown entirely by Canal irrigation and is usually watered at least twice after sowing, the last watering taking place after the plants are in ear. Often before this last irrigation the supply of water in the soil is so small that the plants wilt during the hottest part of the day, the glumes open and the stigmas are exposed to the air. Under such circumstances, in the dry hot climate, natural crossing is easy and it is not surprising therefore that it is so frequent. Experimental cultures might be protected to some extent from natural crossing by more frequent and even watering. Wheat-breeding will always be very difficult at Lyallpur, and it will be necessary to bag the F_1 generation at least. Pure line cultures will have to be rogued every year and frequently re-selected, and the trouble and difficulty of growing pure seed for cultivators will be considerable.

In the damper climate of North Bihár where wheat is grown without irrigation on high moisture retaining loams natural crossing although occurring gives little trouble in selection and breeding work.

It will be evident that the environment may modify to a considerable extent the usual pollination mechanism in a crop. In Northern Europe cross-pollination in wheat is a rare occurrence, in warmer climates it is more frequent while in hot dry localities such as the Canal Colonies of the Punjab where the crop can only be grown by means of artificial irrigation, cross-pollination is quite common.

2. Barley.

A large number of pure line cultures of barley, belonging to different varieties, have been grown at Púsà, but no cases of natural crossing have so far been observed. Natural crossing, however, occurs sparingly in this crop as Rimpau[1] found six cases in eight years.

3. Peas.

In India, as in Europe, the cultivators recognise two great groups of cultivated peas—purple flowered peas (*Pisum arvense*, L., known in India as *kerao*) and white flowered peas (*Pisum sativum*, L., known as *mattar*).

It is generally understood in Europe that in both these groups self-pollination is the rule and that natural cross-fertilization does not take place.[2] Two cases of undoubted natural cross-fertilization have been proved at Púsa between Indian forms of the purple and white flowered groups.

In the case of *kerao*, 28 plants were selected from the harvest of 1909 and sown separately the following October. In 27 cases the progeny was uniform but in one instance splitting took place. Some plants had uniformly green leaves, others were reddish on the margin. Late and early and small and large seeded plants occurred. Seven plants had seeds with black spots only, two plants had seeds with black and brown spots. In this case crossing

1 Rimpau, *Landwirtschaftliche Jahrbücher*, Bd. XX, 1891, s. 357.

2 See *Fruwirth, Die Zuchtung*, Bd. III, 1908, s. 135; Lock, *Annals Royal Botanic Gardens, Peradeniya*, Vol. II, 1904-05: Rimpau, *Land. Jahrbücher*, 1891, s. 366 and Tschermak *Zeit. f. d. land. Versuchswesen in Oesterreich*, Bd. III, 1900, s. 473.

must have taken place between two related types of *Pisum arvense*.

In the case of *Pisum sativum* (*mattar*) 29 single plants were sown in 1909, and at the harvest of 1910 three of these gave rise to mixed offspring. The history of these splitting cases is as follows : In a plot of this crop raised from local seed in 1908 four greenish seeds with black spots were selected. Probably these were taken from a single plant, but on this point we are not certain. However, these four seeds were sown separately in October 1908 and gave rise to four plants as follows :—

Selected from 1908 crop.	Raised in 1908-09.	Raised in 1909-10 from the single plants of 1909.
Four large greenish seeds with black spots.	Flowers white, seed white.	Flowers white, seed white.
	Flowers purple, seed green without spots.	Flowers white, seed white (6). ,, purple, seed green without spots (16).
	Flowers purple, seed green with a few violet spots.	Flowers white, seed white (6). ,, purple — seed green with violet spots (9). ,, purple — seed green without spots (1).
	Flowers purple, seed green with many violet spots.	Flowers white, seed white (4). ,, purple, seed green with violet spots. (17).

Natural crossing has undoubtedly taken place between *mattar* and *kerao*, and as far as we can find, the above is the only case on record of a cross having taken place between purple and white flowered peas. (Plate II.)

4. Khesari. (Lathyrus sativus, L.)

This vetch known as *khesari*[1] is widely cultivated in India for food. We have found no record of any work having been done in India on the pollination of this species. Kirchner[2] observed the honey-bee on cultivated plants in Wurtemburg. When it settled in the middle of the flower, it was dusted with pollen

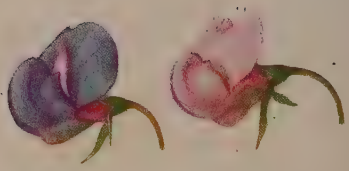
1 Watt, *The Commercial Products of India*, London, 1908, p. 704.

2 Knuth, *Handbook of Flower Pollination*, Vol. II, 1908, p. 334.

THE PROGENY OF A PURPLE-FLOWERED PEA.

PLATE II.

5



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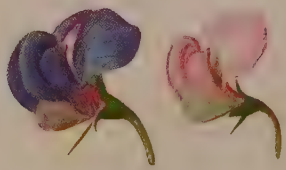


1

NATURAL CROSSING IN KHESARI.

(The numbers refer to the Table opposite.)

on its right side behind the head, and it regularly effected cross-pollination.

It was observed at Púsa in plots raised from local seed that, while the great majority of the plants have blue flowers and breed true, nevertheless a few plants occurred with pink and sometimes reddish flowers.

Ten single plants obtained from a culture raised from pink flowered plants in 1908 were selected in the harvest of 1909 and sown the following October. In 1910 nine of these plants split up as follows :—

	Single plants sown in 1909.	Progeny in 1910.
1	Plant with blue flowers.	Flowers blue (22). Flowers pink (9).
2	Plant with pink flowers.	Flowers blue Flowers blue with a pink border } (7). Flowers pink (12).
3	Do.	Flowers blue Flowers blue with a pink border } (4). Flowers pink (28).
4	Plant with light pink flowers.	Flowers blue (2). Flowers light pink (20).
5	Do.	Flowers blue (3). Flowers light pink (23).
6	Plant with blue flowers.	Flowers blue with pink border ,, ,, without border } (23). Flowers light pink (8). Flowers pink (1).
7	Plant with red flowers.	Flowers red (33). Flowers blue (1).
8	Plant with blue flowers.	Flowers red (6). Flowers blue (22).
9	Do.	Flowers red (5). Flowers blue (23).
10	Plant with red flowers.	Flowers all red. Progeny in all respects like the parent.

Thus nine out of ten single plant cultures split and proved to be natural crosses. Only one red flowered plant bred true. In addition to the differences in the colour of the flowers there were slight differences in the colour of the seeds of the progeny of the crossed plants.

5. Beans.

One case of natural crossing in beans (*Vicia faba*, L.) has been met with at Púsa. In 1909, eight single plants were sown, of which seven bred true and one split as regards the colour of the seeds. The eight cultures belonged to two varieties, one with green seeds the other with black seeds. The four lines with green seeds bred true, one line of the black seeded variety gave six plants with green seed and eight with black or blackish seeds. The other three black seeded lines bred true.

5. Other leguminous crops.

Lentil. The flowers of the lentil (*Lens esculenta*, Moench.) have not yet been studied in detail by us. Eight single plant cultures were made in 1908 and in all cases bred true.

Gram. Several distinct varieties of gram (*Cicer arietinum*, L.) occur mixed together in the crop as ordinarily grown in India. In 1909, 12 single plants were selected which bred true.

San. In *San* (*Crotalaria juncea*, L.) no cases of natural crossing have been observed yet between the two varieties of this crop described by us in a previous paper.[1]

[1] Howard and Howard, *Memoirs of the Department of Agriculture in India* (*Botanical Series*), Vol. III, No. 3, 1910.

III. CROPS WITH OPEN FLOWERS.

1. Tobacco.

Two species of tobacco are cultivated in India, namely, *Nicotiana tabacum*, L., and *N. rustica*, L. The cultivated Indian types of both of these species have been described by us in previous papers[1] and, in addition, the methods of pollination and the frequency of natural cross-fertilization have been studied.

In the flowers of *N. rustica* the anthers always burst in the bud before the corolla opens and the stigma is receptive at the same time. Homogamy is, therefore, the rule. The relative position of the stigma and anthers, however, was found to vary considerably between the various types. The general scheme was found to be as follows: the anthers just before the flowers open are either below, opposite or above the stigma, and in all cases bend towards it. When the pollen is shed, the style elongates and lifts the stigma a little. Then the corolla begins to fade and the anthers recede from the stigma. Every gradation was found in the various types between the condition in which the stamens were above the stigma throughout, rendering cross-pollination practically impossible, and the other extreme case in which all the stamens are so much shorter than the style that self-pollination is only possible by insects or by wind shaking the flowers. Many small bees were noticed visiting the flowers, and some small flies, covered with pollen, were observed inside the corolla tubes. The arrangements for pollination in the various types can be divided into the following three classes (Plate IV) :—

Class I. Stamens much longer than the style.

In this class the style is decidedly shorter than the stamens, so that the four longest stamens bend over the stigma, and in an

[1] Howard and Howard, *Memoirs of the Department of Agriculture in India (Botanical Series)*, Vol. III, Nos. 1 & 2, 1910.

open flower the stigma is not visible, being always covered by the stamens. In such flowers cross-pollination is almost impossible.

Class II. Stamens about the same length as the style.

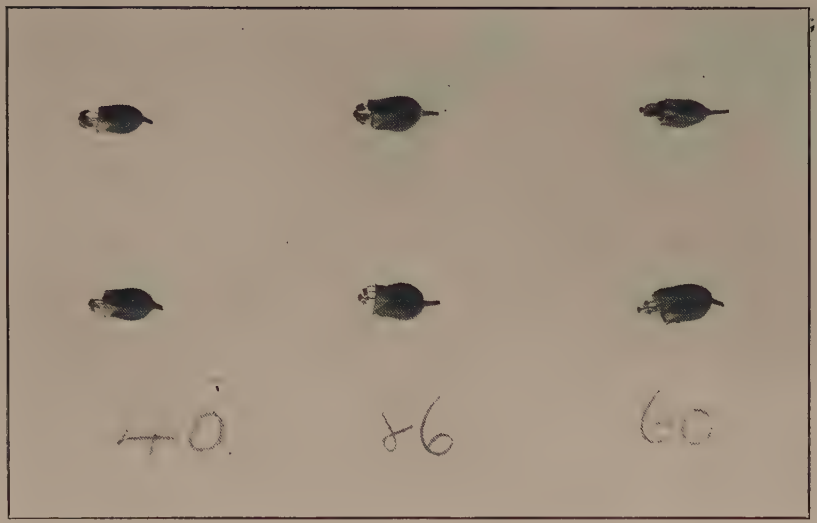
This class includes the various conditions intermediate between classes I and III, and comprises the majority of the types. The stamens may be a very little longer than the style, so that about half the anther projects above the stigma and the latter in the opened flower is surrounded by the burst anthers, but is not obscured by them as in class I. In other cases the tip of the anther only may project above the stigma and the pollen is deposited round its edge just before the corolla opens, while in the fully open flower the empty anthers are clustered round the style just below the stigma. In a few types the anthers may just touch the stigma and the pollen is deposited at its extreme edge or else beneath it. In such cases the anthers are sometimes rather late in bursting and very little pollen is shed before the flower opens.

It is clear that very small differences in the length of the stamens would produce any of these three conditions, and it is not surprising to find that a certain amount of difference can sometimes be found in the flowers of the same plant. For instance, in plants where the anthers normally just touch the stigma, it is usual to find some flowers in which they escape touching it. Thus, in some flowers cross-pollination would be more favoured, in others self-pollination.

Class III. Style much longer than the stamens.

This extreme condition in which the stigma grows out of the unopened bud into the air, and in which self-pollination is exceedingly difficult, was only met with in one case. In this type very few capsules naturally set seed, and it was only possible to obtain seed under bag by artificial selfing.

These observations point to the likelihood of the frequent occurrence, under Indian conditions, of natural cross-fertilization in the field when the types are grown next to next. That natural



SHORT, INTERMEDIATE AND LONG-STYLED FLOWERS
OF N. RUSTICA.

PLATE IV.

crossing actually does take place under these circumstances was proved in a larger number of cases.

Natural Cross-fertilization.

During the year 1905 a collection of Indian tobaccos was made by the Púsa Farm, and the sowings were made the same year. A few plants of each sowing were allowed to run to seed without being bagged, and this seed was again sown in the autumn of 1906. In 1907, we selected seed from all the different plants that could be found in these sowings, and the seed from each plant was sown separately by us the same year. Opportunities for natural cross-fertilization at Púsa were therefore possible for two seasons, 1906 and 1907, before we took over the work. As only a few of the plants, however, were allowed to flower in both years, these opportunities were not numerous. Cross-fertilization, although previously possible in the various tracts of India from which the seed was collected, is not likely to be of frequent occurrence on account of the fact that but few plants are allowed to run to seed by the ryots and that the fields of *N. rustica* are very scattered. In 1908, it was found that out of 45 rows of *N. rustica* each grown from the seed of one plant, 9 were not uniform but contained plants differing from the rest. In 1908, a large number of these aberrant plants were bagged as well as the parent seed plants selected from the uniform rows. The seeds of these plants were again sown separately the same year. In every case the aberrant plants proved to be crosses and gave rise to the most diverse forms (Plate V). In one case infertile plants, with peculiar foliage which may possibly be hybrids between *N. rustica* and *N. tabacum* were observed (Plate VI). The selected plants from the uniform rows however bred true. Natural crossing is therefore frequent in many types of this species, and it will always be necessary in experimental work to obtain seed under bag.

In the Indian types of *N. tabacum* which have been studied up to the present the anthers in the majority of cases burst just as the bud unfolds. In some cases, however, pollination may take

place in the closed bud and in a few cases the anthers burst later when the corolla is half expanded.

The relative positions of the anthers and stigma and consequently the likelihood of self-pollination varies in the different types. The anthers may be below the stigma when they burst and may remain always at a lower level than the stigma making cross-pollination very probable, but this condition is rare. The most usual arrangement is that in which the ripe anthers surround or are just above the stigma when the flower opens. In these cases both cross and self-pollination are possible. In the fully open flowers the burst anthers and stigma may maintain this relative position or the anthers may be as much as 5 mm. above the stigma. In some cases the ripe anthers are well above the stigma in the fully open flower. In one or two types cases were found in which the ripe anthers surrounded the stigma but the latter was well above the empty anthers later.

Another difference was observed in the position of the stigma and anthers with regard to the orifice of the corolla. In some cases the anthers and stigma project into the air far beyond the corolla opening. In other cases the anthers and stigma remain low down in the tube of the corolla. In the majority of the types the anthers are either level with the corolla orifice or project slightly.

The arrangements for pollination in the various Indian types differ somewhat. The majority of the types readily set seed under bag but a few set only it self-pollinated.

Most observers agree that natural cross-fertilization occurs in this species but the extent to which it takes place when the types are grown next to next does not appear to be realised fully. The collection of Indian tobaccos made at Púsa in 1905 was grown for two years on the Púsa farm and a few plants of each kind were allowed to flower freely in 1906 and again in 1907. In 1907, we selected all the different types in this collection, and saved the seed from each plant separately. The various sowings were made by us in the Botanical area at Púsa the same year, and since that time all seed used to propagate the types has been raised under bag. Oppor-

AN EXAMPLE OF NATURAL CROSS-FERTILIZATION IN N. RUSTICA.

PLATE V.

A SECOND EXAMPLE OF NATURAL CROSS-FERTILIZATION
IN N. RUSTICA.

PLATE VI.

tunities for natural crossing were therefore possible at Púsa for two seasons only, and these opportunities were limited by the fact that but few plants of each kind were allowed to flower and the period of flowering of the various kinds did not in all cases overlap. In 1908, observations were made on the uniformity of the cultures raised from one parent plant and any individuals which varied from the rest in the slightest degree were noted. In every case these aberrant plants were selfed and grown the next year when they gave rise to a large number of forms, often very diverse in habit and in leaves and which were obviously the products of natural cross-fertilization. In over a hundred cultures of this species in 1908, about 20 per cent. of the rows contained aberrant plants, thus showing to what a great extent natural crossing is possible when the various kinds are grown in close proximity and allowed to flower freely. Some of the aberrant plants only differed very slightly from the rest of the culture and much care was necessary to distinguish them. Sometimes they appeared only a little more robust than the rest, but in the case of every plant which showed the slightest variation in 1908, its progeny after bagging gave rise to uneven cultures made up of many different types.

Too much emphasis cannot be laid on the difficulty of observing the first generation of a cross between two varieties of tobacco in the field. The differences between many tobacco types are exceedingly small and can only be detected with precision after considerable study in places where such types are grown side by side and allowed to flower. Crosses between types unless they are very different would not be easy to observe in the F_1 generation even in cultures from single plants. In the field, where the great majority of the plants are topped, these differences would, in all probability, be overlooked. In the second and succeeding generations, when splitting takes place, the various types resulting from crossing could for the first time be observed.

In great contrast to the variable character of the progeny of a selfed aberrant plant is the great uniformity of the produce raised from the seed of an ordinary plant raised under bag.

From the practical point of view the significance of natural cross-fertilization in tobacco is very great. We have found at Púsa that natural crossing is the only cause of the breaking up of the type of any desirable kind of tobacco. If crossing is prevented and the type is raised from self-fertilized seed, the uniformity of the crop is extraordinary and no variability as regards the leaves or in time of ripening occurs. Uniformity in the shape, size and texture of the leaves and in the time of ripening is of the greatest importance in tobacco cultivation. Unless the crop ripens off uniformly, the difficulties and expense of harvesting and curing are increased. A crop made up of several types of plant differing in the size, shape, venation, texture and thickness of the leaves does not give a uniform product and unnecessary expense is involved in sorting out the various grades for market. The production and maintenance of the uniformity of the leaf is therefore a matter of the first importance, and is, moreover, the first condition for the improvement of the tobacco crop in India. This improvement can only be maintained by the prevention of natural crossing and by raising all seed under bag. Where a large number of varieties are grown at an experimental farm, the greatest care will have to be taken to keep the types pure and to prevent intercrossing.

The introduction of exotic tobaccos into India and also the testing of those from other localities in India itself are matters intimately associated with natural crossing. It usually happens that introduced seed is impure, giving rise to many types which in some cases resemble each other sufficiently to appear to be homogeneous. No useful purpose is gained by distributing such seed to cultivators. All the various types must first be sorted out, the seed in each case being raised under bag. In this way all crossed plants in the mixture can be eliminated and the best type or types isolated and pure seed distributed. If introduced seed is given to cultivators or used for experiments, it is not improbable that one or more natural crosses or stray plants might be selected as seed parents. In this way the type would be propagated from one or more undesirable plants, and the quality of the kind quickly lost.

2. Patwa. (Hibiscus Cannabinus, L.)

A large number of cultures of the fibre-yielding plant known locally as *patwa* (*Hibiscus cannabinus*) have been grown in the Botanical area at Púsa during the last four years, and some attention has been paid both to the method of pollination and the occurrence of natural crossing.

The flowers of this species open in the early morning before daybreak and begin to close about midday. The closing of the flower is fairly rapid and before sunset the partially withered corollas are twisted up in the manner shown in Plate VII. During the night still further twisting of the corolla takes place, giving rise to the cottage loaf shape of the withered flower shown opposite.

The method of pollination of the flowers of this species is of considerable interest and does not seem to have been studied in detail previously. When the flowers open, the stigmas are at the mouth of the staminal column and the anthers have not yet commenced to burst. Soon after daybreak, the anthers burst and are covered by the large echinulate pollen, the stigmas still remaining flush with the opening of the column. After this the turgidity of the filaments falls off and the burst anthers bend back towards the column. Simultaneously the styles elongate and carry the stigmas into the air beyond the opening of the column, and at this stage pollen grains are rarely seen on the stigmas. Sometimes, however, the styles bend outwards and carry the stigmas on to the pollen, thus bringing about self-pollination. Frequently no pollen is seen on the stigmas when the flowers begin to close about midday. If closed flowers are, however, carefully opened, it is found they are always well pollinated. Self-pollination is effected almost entirely by the closing of the corolla. The limb of the petal is thin, the claw very thick. The corolla closes by the falling towards the centre and twisting of the thin limbs. This brings the corolla in contact with the burst anthers and the completion of the closing of the flowers covers the stigmas with pollen. (Plate VII.)

It will be seen that the flowers are adapted both for cross and self-pollination. From the time the styles begin to carry the stigmas beyond the opening of the column to the closing of the flower crossing is possible. Self-pollination, however, may occur during this period. A sufficient supply of seed is ensured by the very effective method of selfing when the flower closes.

The flowers of this species do not set seed under bag in the ordinary way unless artificially self-pollinated. This is due to the fact that the flower closing mechanism does not act in the bag. The thin limbs of the corolla do not fall together and twist in the normal manner possibly on account of the even humidity of the air both outside and within the closing corolla.

Cross-fertilization is fairly common in this species when the various types are grown next to next and allowed to flower freely. Aberrant plants were found in nearly all the plots raised from the seed of free flowering plants in 1909. These were sown separate early in 1910. In all cases they split up into forms with entire and divided leaves and with variously coloured red and green stems.

3. Roselle. (Hibiscus Sabdariffa, L.)

Natural cross-fertilization does not appear to be equally common in all the cultivated species of the genus *Hibiscus*. Several varieties of Roselle, *Hibiscus sabdariffa*, have been grown next to next at Púsa for four years and not a single instance of natural crossing has been observed even at the edges of the plots where the plants of the varieties touch. Year after year the varieties come true and no crossing has been noticed. The flowers apparently always self-fertilize themselves. The flowers of this species open late in the morning and close at midday remaining open for not more than three hours. The stigmas are throughout flush with the opening of the column and do not grow into the air as in the case of *Hibiscus cannabinus*. The filaments are very short and the anthers burst round the opening of the column. Self-pollination is favoured by these arrangements and the completion of the process is brought about by the closing of the flower. (Plate VIII.)

THE POLLINATION MECHANISM OF HIBISCUS CANNABINUS.

THE POLLINATION MECHANISM OF HIBISCUS SABDARIFFA.

PLATE VIII.

4. Cotton.

Little attention has been paid to cotton from the Botanical point of view by the writers at Púsa as this crop does not thrive in North Bihár. In 1907, a collection of Indian cottons, sent by Professor Gammie from Poona, was sown in the Botanical area at Púsa. These cultures were by no means uniform and appeared to contain several natural crosses. The seed of one of these aberrant plants found in one of the cultures of *Gossypium arboreum*, L., was sown separately in 1908 by Mr. G. P. Hector and gave rise to very variable offspring, clearly proving that the parent plant was of hybrid origin.

The first and most extensive observations on this subject in India have been made by Leake[1] at Cawnpore who sums up his results as follows: "It is as yet impossible to state with certainty to what extent cross-fertilization takes place. The evidence so far obtained indicates that natural crossing occurs with sufficient frequency to render it impossible to keep types pure when they are grown in the proximity of other types." Subsequently Dobbs[2] at Lyallpur independently made some interesting observations on this subject which are best given in the author's own words. He states: "By separate sowing on the farm of seed from single known parents evidence has been obtained, conclusive to anyone familiar with the common reactions caused by hybridization, that a very large proportion of the cottons on the farm, particularly those that are most vigorous, are crosses between distinct varieties within each of the above main types, *e.g.*, seedlings grown from a supposed 'Khaki' American parent having a light brown lint gave 'Khaki,' light brown and pure white lint in approximately Mendelian proportions. Again 'Dharwar' cotton consists, on the farm, of innumerable varieties, early and late, productive and unproductive, of which half do not breed true to type, and it may be inferred that this variation has arisen by hybridization. In

1 Leake, *Journal and Proceedings of the Asiatic Society of Bengal* (*New Series*), Vol. IV, No. 1, 1908, p. 19.

2 Dobbs, *Annual Report of the Lyallpur Agricultural Station for* 1907-08, Lahore, 1908,

this lie great possibilities of improvement by mere systematic selection as well as the explanation of the extraordinary deterioration noted below of Egyptian cotton grown from unselected seed. It is in fact clear that where a valuable variety grows in close proximity to a worthless one of the same main type, great care, in the following year, in the selection of parents for seed production, is necessary if the valuable strain is to be kept pure. This, agreeing with experience in America where (pp. 131 and 132 of the *Yearbook of the U. S. A. Agricultural Department*, 1903) it is advised that seed fields of valuable cotton should be located 'half a mile or more from any other cotton,' should be taken into account in seed-growing in the future.''

Natural crossing in cotton has been observed in other countries. In Egypt, Balls[1] considers that the amount of cross-fertilization which takes place in the Egyptian cotton fields is between five and fifteen per cent. per annum and the accumulated effect of this annual crossing maintains the crop as a mass of natural hybrids. It is not surprising therefore that the introduction of Egyptian cotton seed into Texas has given rise to difficulties which can be entirely explained by the occurrence of natural crossing both previous to and subsequent to the introduction of this crop into America. The American experience, which is no doubt typical, is summed up by Cook[2] in several papers which are of great interest to workers on cotton in India.

5. Linseed.

The information on the subject of the modes of pollination of the cultivated forms of linseed (*Linum usitatissimum*, L.), has been summed up recently by Fruwirth,[3] who states that as a general rule self-pollination is the rule and that good setting is obtained under bag without loss of vigour. While he does not appear to

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1 Balls, *Journal of Agricultural Science*, Vol. II, 1908, p. 378.

2 Cook, *Bulletins* 156 & 157, *Bureau of Plant Industry, U. S. Department of Agriculture*, 1909.

3 Fruwirth, *Die Zuchtung der landw. Kulturflanzen*, Bd. III, 1906, s. 45.

have observed any cases of natural crossing, nevertheless it is pointed out that this is not impossible.

During the last three years a large number of single plant cultures of both European and ordinary Indian linseed have been grown by us next to next in the Botanical area at Púsa. The introduced kinds are those commonly grown for fibre in Europe and are generally characterised by tall, thin, unbranched stems bearing comparatively few capsules. The Indian linseeds are very different in general appearance. They are short much branched forms with thick stems and many capsules.

In 1910 many of these single plant cultures contained tall and short, late and early, many and few seeded plants and in some cases the colour of the flowers of the plants in each culture were markedly different.

Recently attempts have been made in India to introduce the cultivation of linseed for fibre purposes, and for this purpose several consignments of European seed have been grown on the Púsa Farm and at one of the indigo factories in Bihár. It is obviously important to maintain the best fibre-yielding types of linseed uniform. Besides accidental admixture with country linseed the possibility of crossing between the tall fibre-yielding types and the dwarf branched country kinds has to be considered. If this takes place, the uniformity of the type and its value for fibre will quickly be lost.

After three years cultures of single plants of the fibre-yielding linseeds at Púsa we have no doubt that natural crossing takes place under Indian conditions, and that this fact will have to be taken into serious consideration in the growth and distribution of linseed for fibre purposes.

6. The Cruciferous Oil Seeds.

Several species of oil-yielding seeds belonging to the *Cruciferæ* are widely cultivated in India and the seed is an important article of commerce. The oil seeds of Bihár and Bengal belonging to the genus *Brassica* have been studied by Prain,[1] who grew for

[1] Prain, *Agricultural Ledger*, No. 1, 1898.

one year a collection of seed from the various Districts of the Province at Sibpur. He concludes his paper as follows :—

"As regards the relationship that our three mustard oil crops bear to the corresponding crops in Europe, it may be tentatively held :

(1) That *rai* (*Brassica juncea*) is a crop not grown in Europe, at any rate on a commercial scale, but that it takes the place here of *B. nigra* and *B. alba*, which in turn are not grown in India ;

(2) That *sarson* (*B. Campestris* var. *sarson*) is a crop not grown largely if at all in Europe, but that in India it takes the place of both *B. Campestris*, var. *oleifera*, and *B. rapa*, var. *oleifera*, which in turn are hardly ever met with here, finally ;

(3) That *tori* (*B. napus*, var. *dichotoma*) seems to be the same plant as *B. precox* (summer-rape), or if not the same at least very like and very near it, and is undoubtedly the plant that in India takes the place of *B. precox* and of *B. napus* var. *oleifera*."

In the genus *Brassica* according to Knuth,[1] the various species are adapted for cross rather than for self-pollination. Detailed observations on the fertilization of the species cultivated in India do not seem to have been made up to the present.

Indian Mustard or Rai.

A large number of single plant cultures of *rai* have been sown at Púsa. The study of the various forms found in this crop in India is not yet complete nor is the study of the flowers. It is hoped to publish later a detailed account of the botany of the Indian oil seed crops.

Rai readily sets seed under bag and from a consideration of the single plant cultures already studied at Púsa it appears that a good deal of self-pollination naturally takes place.

In 1909, 82 single plants of *rai* were sown at Púsa. Of these 55 bred true and 27 split. Seventeen plants split with regard to the close or open arrangement of the pods (Fig. 3, Plate IX), while 10 split into tall and short plants.

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[1] Knuth, l. c.

Indian Colza or Sarson.

Prain states that there are two races of *sarson* in Bengal—one with erect pods and one with pendent pods. *Sarson* readily sets seed under bag and a certain amount of self-fertilization is therefore to be expected in free-flowering plants.

Forty-eight single plants of white seeded sarson were sown in 1909. The splitting which took place was in two directions, (*a*) as regards the colour of the seeds, red or white, and (*b*) as regards the erect or pendent nature of the pods.

Forty-five out of the 48 plants bred true as regards seed colour, the remaining three giving rise to red and white seeded plants as follows :—

No.	Parent plant, 1909.	Progeny, 1910.	
		Plants with white seed.	Plants with red seed.
1	Seed, white ..	19	2
2	,, ,, ..	23	1
3	,, ,, ..	10	1

The red seeded plants are probably natural crosses in the F_1 generation. These will be sown separately this year and the progeny examined.

Out of eleven plants with pendent pods sown seven bred true and four split as follows (Fig. 2, Plate IX) :—

No.	Parent Plant 1909.	Progeny, 1910.	
		Plants with erect pods.	Plants with pendent pods.
1	Pods pendent ..	1	17
2	,, ,, ..	7	5 (slightly pendent).
3	,, ,, ..	1	13
4	,, slightly pendent ..	8	4

Thirty-seven plants with erect pods were sown and of these 28 bred true, while 9 split into erect and slightly pendent pods as follows :—

No.	Parent plant, 1909.	Progeny, 1910.	
		Plants with slightly pendent pods.	Plants with erect pods.
1	Pods erect	6	18
2	,, ,, ...	8	13
3	,, ,, ...	5	11
4	,, ,, ...	4	13
5	,, ,, ...	9	3
6	,, ,, ...	1	10
7	,, ,, ...	1	23
8	,, ,, ...	2	12
9	,, ,, ...	3	15

In the group of red seeded *sarson* 13 single plants were sown in 1909, six of which split according to seed colour as follows. The rest bred true. In addition to the splitting as regards seed colour most of the cultures varied in the size and arrangement of the pods. (Fig. 1, Plate IX.)

No.	Parent plant, 1909.	Progeny, 1910.	
		Plants with white seed.	Plants with red seed.
1	Seed red	5	15
2	,, ...	7	9
3	,, ...	2	24
4	,, ...	4	24
5	,, ...	4	7
6	,, ...	7	11

Tori or Indian Rape.

The types of *tori* ripen early and considerably in advance of *rai* and *sarson*. Setting under bag is not so easy as in *rai* and *sarson*, and further work is in progress on the method of pollination in this species.

Only two cases of splitting as regards seed colour and habit were met with in 27 single plant cultures made in 1909. One plant gave rise to 3 white seeded plants and 14 red seeded plants. One parent plant with spreading habit gave 3 erect and 12 spreading plants.

NATURAL CROSSING IN RED AND WHITE SEEDED SARSON AND IN RAI.

1. Red seeded Sarson. 2. White seeded Sarson. 3. Rai.

PLATE IX

Taramira (Eruca Sativa, Lam.)

Eruca sativa is extensively cultivated in India as a *rabi* oil seed. Knuth[1] states with regard to this plant: "The flowers are homogamous. The anthers dehisce introsely and are placed so close to the stigma that automatic self-pollination is inevitable." We venture to doubt the correctness of these statements as applied to *taramira* in India. In spite of a large number of trials on well-grown plants at Púsa practically no setting has been obtained under bag. Free-flowering plants, however, set seed freely.

Nine single plant cultures were sown in 1909. In 1910 practically no two plants were alike in any culture. Crossing seems to have taken place in this species in India to an extraordinary extent and the crop seems to be a mass of hybrids in which self-pollination appears to be very rare.

7. Opium Poppy.

Several types of opium poppy (*Papaver somniferum*, L.) are grown in India. In Bihár white flowered types occur, while in Central India purple flowered kinds are cultivated. Forms with entire and more or less divided petals occur, and there are differences in the shape and size of the capsule, in the shape of the leaves and in the hairiness of the stems.

Fruwirth[2] gives a detailed account of the modes of pollination in this species and sums up his own experiments on the subject as well as those of previous observers. The flowers are said to be adapted both for self and cross-pollination, the receptive stigmas being partly self-pollinated before the flower opens. Cross-pollination is effected by insects which visit the flowers to collect pollen. Most observers agree that seed is set under bag, but to a less extent than when the flowers are selfed and still less than when they are allowed to flower freely. This has been our general experience at Púsa with the Indian forms. Fruwirth states that pollinating from different flowers on the same plant or from different plants of the same kind gave as certain setting as free-flowering. The

[1] Knuth, l. c.

[2] Fruwirth, *Die Züchtung*, Bd. II, 1909, s. 178.

capsules in the first case contained more seed than those produced by selfing, while those in the second case were much better. Selfed seed gave fewer plants than free-flowering seed. No loss of vigour from continual selfing seems to have been noticed by this investigator. Forms which stood next to one another and were allowed to flower freely always crossed. Our observations at Púsa in 1909 amply bear out Fruwirth's work on the frequent occurrence of natural crossing in the opium of India.

In 1909, 127 single plants of opium of many different types were sown singly and the progeny in 1910 was examined and gave rise to mixed offspring, only 9 plants breeding true. Splitting took place in many directions, for example, into divided and nearly entire leaves, round or oblong capsules, hairy and smooth stems, in colour of the margin and eye of the petals and in the amount of division of the petals.

As regards the amount of division of the leaves two good cases of splitting were observed :—

No.	Parent plant, 1909.	Progeny, 1910.	
		Deeply divided.	Slightly divided.
4/136	Leaves slightly divided	14	43
4/134	,, ,, ...	29	61

Usually smooth stemmed plants bred true. Almost all the hairy stemmed plants gave smooth and variously hairy plants.

A great deal of splitting was observed as regards the colour of the petals (Plates X & XI). Out of 35 single plants with white petals with an entire margin, 14 bred true and 21 split. Splitting took place both with regard to colour and to the character of the margin whether entire or divided. As a rule the flowers with entire white petals which split gave white and light red petals. Plants with divided petals generally bred true but colour differences often came in. Thus out of 12 plants with white divided petals in 1909 only three bred true in every respect, but, as regards divided petals only, 10 came true.

THE PROGENY OF A PLANT OF OPIUM POPPY WITH VIOLET DIVIDED PETALS.

THE PROGENY OF A PLANT OF OPIUM POPPY WITH ENTIRE RED PETALS.

Enough has been said to show that it is impossible to grow a collection of Indian poppies side by side for experimental purposes and to allow them to flower freely. In a single season the various cultures would be contaminated to such an extent by vicinism that further work would lead to no result. A collection of poppy seeds from the various districts of India was sown at Púsa in 1908 and 1909 showed that except in the case of seed from the United Provinces each set of seed gave rise to mixed plots and it appeared probable that crossing goes on to a great extent in the cultivators' fields themselves and that the present opium crop is often largely composed of hybrids.

8. Safflower.

Safflower (*Carthamus tinctorius*, L.) is widely cultivated in India both for the dye in its flowers and for the oil in the seeds. Even a casual examination of the crop as grown by the cultivators shows that a very large number of forms are to be seen in the same field.

Some setting is obtained under bag. Out of 800 heads bagged in 1909 only 181 produced seeds and the number of seeds in each case was far below that obtained in free-flowering heads.

In 1910 the amount of setting obtained under bag was carefully determined in the case of eight plants. The results are given in the following table :—

No.	No. of heads bagged.	No. of heads which formed seed.	No. of seeds formed.	No. of seeds in unbagged heads.
1	10	3	32	356
2	13	8	63	489
3	12	11	131	402
4	10	6	54	404
5	9	8	169	323
6	11	8	99	697
7	10	6	53	516
8	10	7	139	488
Total	85	57	740	3,669

It will be seen that only 67 per cent. of the heads formed seed, while the total amount of seed was only 20 per cent. of what would have set if the heads had not been bagged.

Seventy-six single plants raised from one sample of local seed were sown in 1909 and out of these only two have bred true in all respects. In this crop, therefore, we have to deal with a plant which normally crosses and the point to determine is not how much crossing, but how frequently self-pollination takes place.

Splitting took place in many directions, namely, in the colour of the flowers, in the habit of the plants, whether tall or spreading, in the felting or smoothness of the heads, and in the character of the leaves and bracts. (Plate XII.)

The colour of the flowers may be yellow, or various shades of orange turning into red when the flowers wither. Yellow flowers when fading give a dirty yellow colour. As an example of splitting in flower colour the progeny of two yellow and 2 orange flowered plants selected in 1908 may be given. (Plate XIII.)

No.	Parent plant, 1909.	Progeny, 1910.
1	Orange flowers ...	Yellow flowers (2). Light orange flowers (1). Orange flowers (2).
2	„ „ ...	Yellow flowers (1). Light orange flowers (1). Orange flowers (1).
3	Yellow flowers ...	All yellow flowers.
4	„ „ ...	Yellow flowers (2). Light orange (1). Orange flowers (1).

Nine other plants split into orange and light orange flowered plants.

As regards the felting of the buds nine cases of splitting occurred and 12 good examples of splitting according to the erect or spreading habit were noted. Splitting also took place according to the character of the leaves (spiny or spineless), bracts and as regards time of maturity (early and late). Taking into consideration all these points only two cultures bred true.

THE PROGENY OF A SINGLE PLANT OF SAFFLOWER.

PLATE XII.

THE PROGENY OF A SELF-POLLINATED PLANT OF SAFFLOWER WITH ORANGE FLOWERS.

PLATE XIII.

IV. MONOECIOUS AND DIOECIOUS CROPS.

Maize, as is well known, is largely cross-fertilized. Many breeders at the present time are agreed that not only is continuous self-pollination injurious to the crop but that the best chances of improvement lie in breeding on a broad basis and in permitting natural crossing to take place within limits. The uniformity which is possible in narrow breeding is likely to be of less importance than the vigour and consequent increased yield which results from crossing within broad limits. Yield is likely to be of greater importance than uniformity.[1,2]

Our observations on crops of this group are limited to castor (*Ricinus communis*, L.). In 1908, ten single plant castor cultures were made from plots grown at Púsa the previous year from various samples of local Bihár seed and from two samples of castor from Africa. In all cases the cultures showed that natural crossing had taken place, a result which was fully expected. Any attempt to introduce into India an exotic variety of this crop, however excellent, could have little effect as its qualities would quickly be lost through crossing with the indigenous crop.

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[1] Collins, *Bull. 141, Bureau of Plant Industry, U. S. Dept. of Agr.*, 1909.

[2] Shull, *The Composition of a field of Maize*, American Breeders' Association, vol. 4.

V. THE BEARING OF NATURAL CROSS-FERTILIZATION ON THE IMPROVEMENT OF INDIAN CROPS.

The extent to which natural cross-fertilization occurs in India is of great importance to and is closely bound up with the improvement of the crops of the country. The extent to which natural crossing takes place largely determines the methods which can be adopted in improving a crop, it influences the introduction of exotics, the testing of varieties and the distribution of seed to cultivators. In taking up any crop therefore the first condition for successful work is a study of the method of pollination and the extent to which natural crossing takes place. Based on accurate information on these matters the application of correct methods of improvement is almost bound to lead to success. It is proposed to discuss briefly the precise bearing of the facts brought forward in the present paper on the choice of the methods of improvement, on the introduction of exotics, on the testing of varieties and also on seed distribution.

The significance of natural crossing from the systematic standpoint must not be forgotten. It is obvious that great care must be exercised in assigning a varietal position to any aberrant forms met with unless they have been shown to breed true from seed. In many cases where natural crossing occurs, these forms are likely to be mere Mendelian combinations of the characters of two existing species or varieties which in the next generations would give rise to a large series of forms.[1]

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1 Since this paper was written some interesting observations on this subject have been made in England by Henry (*Gardeners' Chronicle*, Apr. 23 and 30, 1910). This investigator has shown that many aberrant forms of forest trees which were formerly regarded as varieties or even as distinct species are nothing more than first crosses.

1. The methods of Improving Crops.

Cook[1] in a recent paper has discussed the broad lines of plant improvement. He distinguishes three main methods which are described as follows :—

"*Broad breeding* is the condition of descent found in natural species, which consist of millions of diverse individuals freely interbreeding with each other so that the vast number of lines of descent of the species are joined into a broad network.

Narrow breeding is the condition of descent found in carefully selected varieties, consisting of relatively small numbers of closely similar individuals interbreeding with each other to form a narrow network of descent.

Line breeding is the condition of descent found in strains descended from single individuals propagated without interbreeding with other lines of descent so that no network is formed." Cook regards vegetative propagation, parthenogenesis, self-fertilization and in-and-in breeding as forms of line breeding.

Line breeding or growth from single plants is the method applicable to crops which are usually self-pollinated such as the cereals and pulses or to crops like tobacco where uniformity is the first consideration and where crossing is easily prevented and a large supply of self-pollinated seed is a simple matter. If natural crossing occurs however to an appreciable extent, as, for example, in wheat at Lyallpur, occasional continued selection in the pure line cultures will be necessary in addition to roguing. In this way the purity of the types can be ensured and the effects of crossing eliminated.

Broad breeding is the method essentially applicable to crops like maize where yield and vigour are more important than uniformity.

In crops like cotton, and the *Brassica* oil seeds, where a certain amount of crossing takes place, the choice seems to lie between broad and narrow breeding. Propagation in pure lines, besides

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1 Cook, *Bull. 146, Bureau of Plant Industry, U. S. Dept. of Agr.*, 1909.

its difficulty, might lead to loss of vigour and it may well be an advantage to sacrifice absolute uniformity to yield. How far a crop in which, say, from 5 to 10 per cent. of natural crossing takes place, can be propagated successfully without loss of vigour from a single fixed plant obtained either by selection or as the result of hybridization is a matter which, at the present time, calls for long-continued and accurate experiment. Can the method of single plant selection be applied to crops like the *Brassica* oil seeds or to cotton and natural crossing be avoided without loss of vigour? If so, the study of pure lines can be applied to such crops. The whole matter turns on the possible ill-effects of in-and-in breeding in such crops and on the practical difficulties in the prevention of vicinism.

The extent to which natural crossing takes place obviously affects the production of new varieties by hybridization and the study of the inheritance of characters. Even when spontaneous crossing is rare its possible effects on the various hybrid generations must be expected. In crops where crossing frequently takes place the difficulties are greatly increased if accurate and trustworthy results are to be obtained. Some years must necessarily elapse before pure line cultures can be obtained and the splitting forms eliminated. After the crosses have been made all subsequent work will have to be done with bagged plants so as to exclude the effect of natural crossing.

2. The Introduction of Exotics.

Natural crossing has obviously an important bearing on the introduction of exotics. If crossing takes place in a crop, it is likely that any consignment of seed from another country will not be uniform but will contain hybrids. The seed must first be grown, if possible apart from similar local crops, and the constitution of the crop determined. Methods of selection may in consequence have to be applied, and some years may elapse before any of the seed can be distributed to cultivators. The recent failure of the introduction of Egyptian cotton into Texas[1] appears to have

[1] Cook, *Bull. 156, Bureau of Plant Industry, U. S. Dept. of Agr.*, 1909,

been due to the fact that it was not understood that the cotton crop in Egypt is a mass of hybrids some of which are exceedingly undesirable. Two difficulties therefore face the introducer of an exotic in which natural crossing occurs. The introduced crop is almost certain to contain splitting forms, some probably undesirable. Further the exotic will probably cross with the local crops.

The effects of natural crossing in the introduction of exotics are often erroneously attributed to the influence of acclimatisation. It is obvious that the effects of acclimatisation can only be studied in a crop in which natural crossing is altogether prevented.

3. The testing of varieties.

Varieties can only be safely collected and tested side by side at an Experiment Station if cross-fertilization either does not occur at all or to so small an extent that an occasional rogueing of the plots is sufficient to keep them pure or if, as in tobacco, it can be prevented altogether by artificial means. Variety trials of crops like maize and castor oil are difficult on account of the certainty of contamination by vicinism. Much useless work is continually being done in the trial of varieties which cross among themselves. The constitution of the crop and therefore the yields change from year to year and the results are erroneously attributed to the varying influence of the season.

4. The Distribution of Seed.

The final outcome of the improvement of any crop in India is naturally the growth for distribution to the cultivators of improved and tested seed. The investigator, not unnaturally, is anxious to begin this work at the earliest possible moment as it is regarded as a proof of the successful consummation of his efforts. In crops like wheat and tobacco there are no particular difficulties in the seed supply except in distributing wheat in the Canal Colonies of the Punjab where natural crossing is comparatively common. A large supply of self-fertilized tobacco seed is easily produced, and the scattered nature of the cultivation and the few plants kept for

seed will greatly limit crossing in the Districts. In other crops, however, where crossing is more frequent, the improved seed, even if kept pure on the seed farms, will soon lose its qualities through vicinism when grown by the people. Unless some co-operative arrangement can be devised and put into practice by which an improved variety entirely replaces the old in a locality, the good done by seed distribution in such crops can easily be exaggerated.

PUSA,
March 1910.

Note added.—While this paper was passing through the press a large number of single plant cultures of *til* (*Sesamum indicum*, L.) and of *niger* (*Guizotia abyssinica*, L.) have been grown at Pusa. In both these crops natural cross-fertilization has been found to occur to a considerable extent the details of which will be published in a subsequent paper.

PUSA,
Oct. 14th, 1910.